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Random Valued Impulse Noise Removal Using Fuzzy Techniques

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ABSTRACT – A fuzzy filter for the removal of random impulse noise in color video is presented. By working with successive filtering steps, a very good tradeoff between detail preservation and noise removal is obtained. Therefore, the noise is filtered step by step. In each step, noisy pixels are detected by the help of fuzzy rules. Pixels that are detected as noisy are filtered, the others remain unchanged. Filtering of detected pixels is done by median filtering techniques. The proposed method outperforms other filters both visually and in terms of objective quality measures such as the mean absolute error (MAE), and the peak-signal-to-noise ratio (PSNR).

Index Terms—Circuits and systems, computers and information processing, filtering, filters, fuzzy logic, image denoising, logic, nonlinear filters.

I. INTRODUCTION

Images and videos belong to the most important information carriers in today's world. However, the images are likely to be corrupted by noise due to bad acquisition, transmission or recording. Such degradation negatively influences the performance of many image processing techniques and a preprocessing module to filter the images is often required. Among those filters, more and more fuzzy techniques start to appear in literature [3], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]. Fuzzy set theory was introduced by Zadeh in 1965 and is a generalization of classical set theory.

Most filters in literature, that are developed for video, are intended for sequences corrupted by additive Gaussian noise. Only few video filters for the impulse noise case can be found. However, several impulse noise filters for still images exist. The best known among them are the median based rank-order filters. Such 2-D filters could be used to filter each of the frames of a video successively. However, temporal inconsistencies will arise due to the neglecting of the temporal correlation between successive frames. A better alternative would be to use 3-D filtering windows, in which also pixels from neighboring frames are taken into account. The main problem in using neighboring frames is motion between them. Using pixels at corresponding spatial positions in neighboring frames for noise removal may introduce ghosting artifacts in the presence of camera and object motion. In the method proposed in this paper, we will therefore only in non-moving areas assign a temporal impulse between two corresponding spatial positions to noise (detection phase) and for the replacement of a noisy pixel (filtering phase) motion compensation will be applied to find the most reliable pixel in the previous frame.

In this paper, we present a filter for the removal of random impulse noise in color image sequences, in which each of the color components is filtered separately based on fuzzy rules, in which information from the other color bands is integrated. To preserve the details as much as possible, the noise is removed by three successive filtering steps. Only pixels that have been detected to be noisy are filtered. This filtering is done by median filtering techniques.

The paper is structured as follows. The successive filtering steps of the proposed filter are discussed in Section II. In Section III Objective Quality Measures is presented. In Section IV, simulation results and statistical analysis of PSNR values is carried out. The paper is concluded in Section V.

II.THE PROPOSED ALGORITHM

The filtering framework presented in this paper is intended for color video corrupted by random impulse noise. If we respectively denote the original (noise-free) sequence by I_0, the t_{th} frame of that sequence by $I_0(t)$ and the red, green and blue component of the color $I_0(x,y,t)$ of the pixel at the X_{th} row and Y_{th} column in that frame by $I_0^R(x,y,t)$, $I_0^G(x,y,t)$ and $I_0^B(x,y,t)$ then the noisy sequence is determined as follows [1], [2]:

$$I_n^c(x,y,t) = \begin{cases} I_0^c(x,y,t), & \text{with probability } 1-p, \\ \eta^c(x,y,t), & \text{with probability } p \end{cases} \quad \ldots\ldots(1)$$

Where c belongs to {R,G,B} and p belongs to [0,1] denotes the probability that a pixel component value is corrupted and replaced by a identically distributed independent random noise value $\eta^c(x,y,t)$.

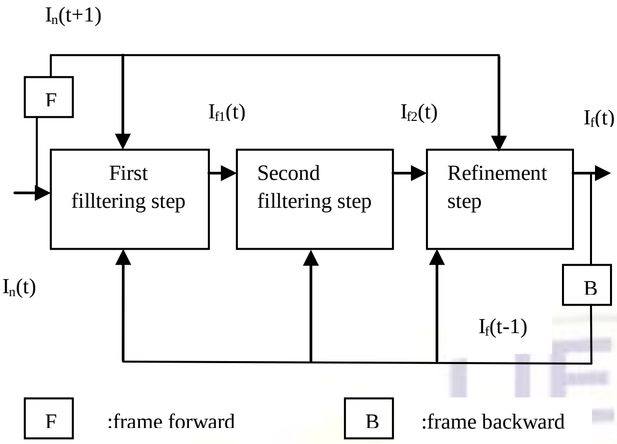

Fig 1. Overview of different steps in the proposed algorithm

The proposed filtering framework consists of three successive filtering steps as depicted in Fig. 1. In the first step, we calculate for each pixel component a degree to which it is considered noise-free and a degree to which it is considered noisy. If the noisy degree is larger than the noise-free degree, the pixel component is filtered, otherwise it remains unchanged.

Analogously as to the first step in the second step, again a noise-free degree and a noisy degree are calculated. However, the detection is now mainly based on color information. A pixel component can be seen as noisy if there is no similarity to its (spatio-temporal) neighbors in the given color, while there is in the other color bands. The third step, finally, removes the remaining noise and refines the result by using as well temporal as spatial and color information.

A. FIRST FILTERING STEP

(1) Detection: In this detection step, the noise-free degree and the noisy degree are determined by fuzzy rules as follows. For the noise-free degree of the red component (and analogously for the other components), this is achieved by the following fuzzy rule.

Fuzzy Rule 1: IF(($|I_n^R(x,y,t) – I_f^R(x,y,t-1)|$ is NOT LARGE POSITIVE OR $|I_n^R(x,y,t) – I_n^R(x,y,t+1)|$ is NOT LARGE POSITIVE) AND there are two neighbors $(x+k,y+l,t)$ ($-2 \leq k,l \leq 2$ and $(k,l) \neq (0,0)$) for which $|I_n^R(x,y,t) – I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE)

OR (there are four neighbors $(x+k,y+l,t)$ ($-2 \leq k,l \leq 2$ and $(k,l) \neq (0,0)$) for which $|I_n^R(x,y,t) – I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE OR (there are two neighbors $(x+k,y+l,t)$ ($-2 \leq k,l \leq 2$ and $(k,l) \neq (0,0)$) for which $|I_n^R(x,y,t) – I_n^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE AND ($I_n^G(x,y,t) – I_n^G(x+k,y+l,t)$ OR $|I_n^B(x,y,t) – I_n^B(x+k,y+l,t)$ are NOT LARGE POSITIVE)))

Then the red component $I_n^R(x,y,t)$ is considered NOISEFREE.

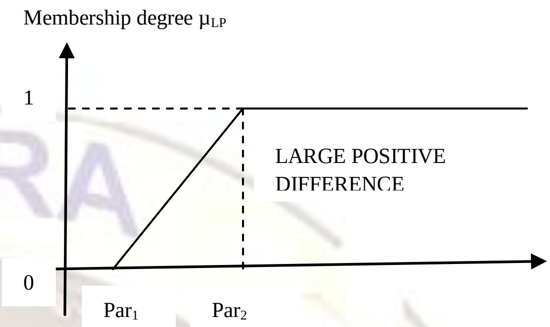

Fig 2. Membership function μ_{LP} of fuzzy set large positive

To represent the linguistic value large positive in the above rule, a fuzzy set is used, with a membership function as depicted in Fig. 2. The degree to which the red component of the pixel at position (x,y,t) is considered noise-free, is determined as

$\mu^R_{noisefree}(x,y,t) = \max(\min(\max(\alpha_1(x,y,t), \alpha_2(x,y,t)), M_2(x,y,t)), \max(M_4(x,y,t), M_{2b}(x,y,t)))$ …….(2)

where $\alpha_1(x,y,t) = (1 - \mu_{LP}(|I_n^R(x,y,t) – I_f^R(x,y,t-1)|))$,

$\alpha_2(x,y,t) = (1 - \mu_{LP}(|I_n^R(x,y,t) – I_n^R(x,y,t+1)|))$,

and where $M_2(x,y,t)$ and $M_4(x,y,t)$ respectively denote the degree to which there are two (respectively four) neighbors for which the absolute difference in the red component value is not large positive.

$\{1 - \mu_{LP}(|I_n^R(x,y,t) – I_n^R(x+k,y+l,t)|)||$

$-2 \leq k,l \leq 2$ and $(k,l) \neq (0,0)\}$

Analogously, a degree to which the component of a pixel is considered noisy is calculated. For the red component (and analogously the other components) this leads to the following fuzzy rule.

Fuzzy Rule 2: IF($|I_n^R(x,y,t) – I_f^R(x,y,t-1)|$ is LARGE POSITIVE AND NOT (for five neighbors $(x+k,y+l,t)$ ($-2 \leq k,l \leq 2$ and $(k,l) \neq (0,0)$) $|I_n^R(x+k,y+l,t) – I_f^R(x+k,y+l,t-1)|$ is LARGE POSITIVE AND ($|I_n^G(x+k,y+l,t) – I_f^G(x+k,y+l,t- 1)|$ OR $|I_n^B(x+k,y+l,t) – I_f^B(x+k,y+l,t-1)|$ is LARGE POSITIVE)))

AND ((in one of the four directions(the differences $I_n^R(x,y,t) – I_n^R(x+k,y+l,t)$ AND $I_n^R(x,y,t) – I_n^R(x-k,y-l,t)$ ($(k,l) \in \{(-1,-1), (-1,0), (-1,1), (0,1)\}$) are both LARGE POSITIVE OR both LARGE NEGATIVE) AND the absolute difference $|I_n^R(x+k,y+l,t) – I_n^R(x-k,y-l,t)|$ is NOT LARGE POSITIVE) OR ($I_n^G(x,y,t)$ –

$I_f^G(x,y,t-1)|$ is NOT LARGE POSITIVE OR $I_n^B(x,y,t) - I_f^B(x,y,t-1)$ is NOT LARGE POSITIVE))

THEN the red component is considered noisy. The linguistic term large negative is represented by a fuzzy set, characterized by the membership function given in the Fig. 3

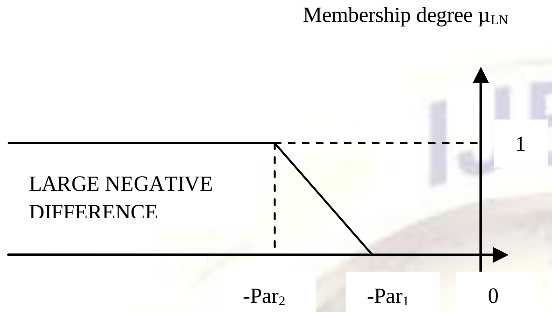

Fig 3. Membership function μ_{LN} of fuzzy set large negative

The degree to which the absolute difference between the pixel at position (x,y,t) and the corresponding pixel in the previous frame is large positive is given by
$\beta(x,y,t) = \min(\mu_{LP}(|I_n^R(x,y,t) - I_f^R(x,y,t-1)|),\ 1-t_{pos}(x,y,t))$. …….(3)

Further the degree to which there is no large difference between the considered pixel and the pixel at the same spatial location in the previous frame in one of the other two color bands is given by
$\delta(x,y,t) = \max(1-\mu_{LP}(|I_n^G(x,y,t) - I_f^G(x,y,t-1)|),\ 1-\mu_{LP}(|I_n^B(x,y,t) - I_f^B(x,y,t-1)|))$. …….(4)

Finally, the degree to which there is a direction in which the pixel at position (x,y,t) is an impulse, denoted by $\gamma(x,y,t)$ is determined as
$\{\min(\max(\epsilon^1_{(k,l)}(x,y,t),\epsilon^2_{(k,l)}(x,y,t)),\epsilon^3_{(k,l)}(x,y,t)) \,||(k,l) \in \{(-1,-1), (-1,0), (-1,1), (0,1)\}\}$

Finally the noisy degree is calculated by combining the above equations and it is given by

$\mu^R_{noisy}(x,y,t) = \min(\beta(x,y,t), \delta(x,y,t), \gamma(x,y,t))$. ….(5)

(2) Filtering: In this subsection, we discuss the filtering for the red color band. The filtering of the other color bands is analogous. We decide to filter all red pixel components that are considered more likely to be noisy than noise-free.

$$\mu^R_{unch}(x,y,t) = \begin{cases} 0, & \text{if } \mu^R_{noisy}(x,y,t) \succ \mu^R_{noisefree}(x,y,t) \\ 1, & \text{else} \end{cases}$$
…….(6)

The output of this first step for the red component is given as follows.
IF $\mu^R_{unch}(x,y,t) = 1$, then $I_{f1}^R(x,y,t) = I_n^R(x,y,t)$,
else if $\mu^R_{unch}(x,y,t) = 0$, then the filtering of the red color band (analogously other color bands) is done using median filtering techniques.

Median filtering is a nonlinear operation often used in image processing to reduce "salt and pepper" noise. A median filter is more effective than convolution when the goal is to simultaneously reduce noise and preserve edges.

B = medfilt2(A, [m n]): performs median filtering of the matrix A in two dimensions. Each output pixel contains the median value in the m-by-n neighborhood around the corresponding pixel in the input image. medfilt2 pads the image with 0s on the edges, so the median values for the points within [m n]/2 of the edges might appear distorted.
B = medfilt2(A) performs median filtering of the matrix A using the default 3-by-3 neighborhood.
B = medfilt2(A, 'indexed', ...) processes A as an indexed image, padding with 0s if the class of A is uint8, or 1s if the class of A is double.
B = medfilt2(..., padopt) controls how the matrix boundaries are padded. padopt may be 'zeros' (the default), 'symmetric', or 'indexed'. f padopt is 'symmetric', A is symmetrically extended at the boundaries. If padopt is 'indexed', A is padded with ones if it is double; otherwise it is padded with zeros.

B. SECOND FILTERING STEP

In this step, the noise is detected based on the output of the previous step. For the red component (and analogously the other color components), the noise-free degree is calculated based on the following fuzzy rule.
Fuzzy Rule 3: IF($|I_{f1}^R(x,y,t) - I_f^R(x,y,t-1)|$ is NOT LARGE POSITIVE AND ($|I_{f1}^G(x,y,t) - I_f^G(x,y,t-1)|$ is NOT LARGE POSITIVE OR $|I_{f1}^B(x,y,t) - I_f^B(x,y,t-1)|$ is NOT LARGE POSITIVE)

OR(for two neighbors (x+k,y+l,t) ($-1 \le k,l \le 1$ and $(k,l) \neq (0,0)$) $|I_{f1}^R(x,y,t) - I_f^R(x+k,y+l,t)|$ is NOT LARGE POSITIVE AND ($I_{f1}^G(x,y,t) - I_f^G(x+k,y+l,t)|$ is NOT LARGE POSITIVE OR $|I_{f1}^B(x,y,t) - I_f^B(x+k,y+l,t)|$ is NOT LARGE POSITIVE))

Then the red component is considered NOISE-FREE.The Noise-Free degree is calculated as given below
$\mu^R_{2,noisefree}(x,y,t) = \max(\zeta(x,y,t), \eta(x,y,t))$ …..(7)

$\zeta(x,y,t)$

$= \min(1-\mu_{LP}(|I_{f1}^R(x,y,t) - I_f^R(x,y,t-1)|),$
$\max(1-\mu_{LP}(|I_{f1}^G(x,y,t) - I_f^G(x,y,t-1)|),$
$1-\mu_{LP}(|I_{f1}^B(x,y,t) - I_f^B(x,y,t-1)|)))$
and $\eta(x,y,t)$ is the second largest element in the set

$\{\min(1-\mu_{LP}(|I_{f1}{}^{R}(x,y,t)–I_{f}{}^{R}(x+k,y+l,t)|), \max(1-\mu_{LP}(|I_{f1}{}^{G}(x,y,t)–I_{f}{}^{G}(x+k,y+l,t)|),1-\mu_{LP}(|I_{f1}{}^{B}(x,y,t) – I_{f}{}^{B}(x+k,y+l,t)|)))$

$||-1 \leq k,l \leq 1$ and $(k,l) \neq (0,0)\}$.

For the red component (and analogously the other color components), the noisy degree is calculated based on the following fuzzy rule.

Fuzzy Rule 4: IF (for three neighbors (x+k,y+l,t) ($-1 \leq k,l \leq 1$ and $(k,l) \neq (0,0)$) $|I_{f1}{}^{R}(x,y,t) – I_{f}{}^{R}(x+k,y+l,t)|$ is LARGE POSITIVE AND $|I_{f1}{}^{G}(x,y,t) – I_{f}{}^{G}(x+k,y+l,t)|$ is NOT LARGE POSITIVE AND $|I_{f1}{}^{B}(x,y,t) – I_{f}{}^{B}(x+k,y+l,t)|$ is NOT LARGE POSITIVE)

THEN the red component is considered NOISY. The noisy degree for the red component is calculated as follows:

$\mu^{R}_{2,noisy}(x,y,t) = \max(\theta(x,y,t), \kappa(x,y,t))$ ……..(8)

$\theta(x,y,t)$ is given as

$\{\min(\mu_{LP}(|I_{f1}{}^{R}(x,y,t)–I_{f}{}^{R}(x+k,y+l,t)|), \min(1-\mu_{LP}(|I_{f1}{}^{G}(x,y,t)–I_{f}{}^{G}(x+k,y+l,t)|), 1-\mu_{LP}(|I_{f1}{}^{B}(x,y,t) – I_{f}{}^{B}(x+k,y+l,t)|)))$

$||-1 \leq k,l \leq 1$ and $(k,l) \neq (0,0)\}$

Analogously to the first step, the filtering of the red components (and analogously the green and blue components) is given as if $\mu^{R}_{2,unch}(x,y,t) = 0$, the $I_{f1}{}^{R}(x,y,t)$ is filtered using median filter.

C. THIRD FILTERING STEP

The result from the previous steps is further refined based on temporal, spatial and color information. Namely, the red component of a pixel is refined in the following cases:

- In non-moving areas, pixels will correspond to pixels in the previous frame, which allows us to detect remaining isolated noisy pixels.If $|I_{f2}{}^{R}(x,y,t) – I_{f}{}^{R}(x,y,t-1)| > par_2$ and $|I_{f}{}^{R}(x,y,t-1) – I_{n}{}^{R}(x,y,t+1)| < par_1$ then the red component is considered to be noisy.
- Very small impulses might not have been detected by the algorithm. In homogeneous areas however, such impulses might be relatively large and can be detected more easily. Let $L^{R}_{2}(x,y,t)$ and $S^{R}_{2}(x,y,t)$ respectively denote the second largest and second smallest red component value among the eight neighbors in a 3x3 neighborhood around $I^{R}_{f2}(x,y,t)$. If $L^{R}_{2}(x,y,t) - S^{R}_{2}(x,y,t) < par_2$ (homogeneous neighborhood) and further also $I^{R}_{f2}(x,y,t) - L^{R}_{2}(x,y,t) > L^{R}_{2}(x,y,t) - S^{R}_{2}(x,y,t)$ or $S^{R}_{2}(x,y,t) - I^{R}_{f2}(x,y,t) > L^{R}_{2}(x,y,t) - S^{R}_{2}(x,y,t)$ (the red component is clearly larger or smaller than the neighborhood), then the red component $I^{R}_{f2}(x,y,t)$ is considered to be noisy ($\mu^{R}_{3,unch}(x,y,t) = 0$).
- Based on color information, the red component is considered to be noisy if in a 3×3 neighborhood two neighbors can be found for which $|I_{f2}{}^{R}(x,y,t) – I_{f2}{}^{R}(x+k,y+l,t)| > par_2$

In all other cases the red component value is considered to be noise-free. Analogously as in the previous steps, the red component for which $\mu^{R}_{3,unch}(x,y,t) = 0$ is filtered using median filter. Otherwise it remains unchanged.

III.OBJECTIVE QUALITY MEASURES

To be able to judge the performance of the proposed method,we will use the mean absolute error (MAE),the peak-signal-to noise ratio (PSNR) asobjective measures of similarity and dissimilarity between a filtered frame and the original one .

The MAE is given by

$$MAE(I_0(t), I_f(t)) = 1/3.n.m \sum_{c\in\{R,G,B\}} \sum_{x=1}^{m}\sum_{y=1}^{n} | I_0^c(x,y,t) - I_f^c(x,y,t) | \quad \text{………(9)}$$

The lower the MAE, the more similar (less dissimilar) the images.

The PSNR value is defined as

$$PSNR(I_0(t), I_f(t)) = 10.\log_{10}\frac{S^2}{MSE(I_0(t), I_f(t))} \quad \text{………(10)}$$

$$MSE(I_0(t), I_f(t)) = 1/3.n.m \sum_{c\in\{R,G,B\}} \sum_{x=1}^{m}\sum_{y=1}^{n} (I_0^c(x,y,t) - I_f^c(x,y,t))^2 \quad \text{…….(11)}$$

The higher the PSNR value, the more similar (less dissimilar) the images.

A. Parameter Selection

The parameters par_1 and par_2 that determine the membership functions μ_{LP} and μ_{LN} in Fig. 2 and Fig. 3 are fixed as $(par_1, par_2) = (18,29)$.

IV. SIMULATION RESULTS

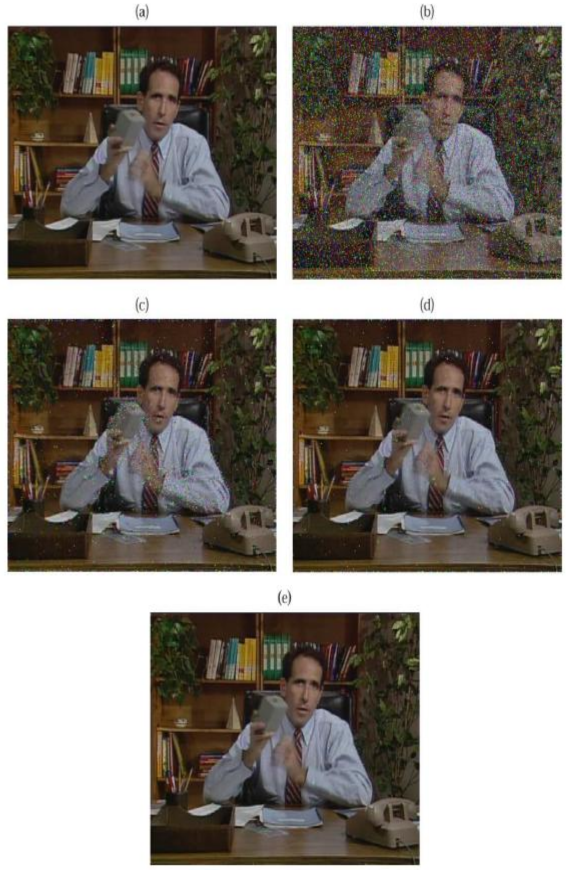

Fig 4. The original 20th frame of the "Salesman" sequence (a), the frame corrupted by 20% random impulse noise (b) (PSNR=36.1248 dB) and the result after the first (c) (PSNR=43.7062 dB), second (d) (PSNR=48.6028 dB) and refinement step (e) respectively.

The results of the different successive filtering steps are illustrated for the 20th frame of the "Salesman" sequence in Fig. 4. In Fig. (c) that is the output of first filtering step large no.of noisy pixels are filtered. The remaining noisy pixels are filtered in the second step as can be seen in Fig. (d). Most of the noisy pixels are filtered in this stage. In the final step the remaining isolated noisy pixels are filtered and the result is refined in this step. The output of third step can be seen in Fig. (e).

Fig. (a) is the original 20_{th} frame of the "Salesman" sequence. Figure (b) represents the frame corrupted by 20% random impulse noise. Figure (c) is the result after the first filtering step (PSNR= 36.1248 dB). Figure (d) is the result after the second filtering step (PSNR= 43.7062 dB). Figure (e) is the result after the third filtering step that is the refinement step (PSNR= 48.6028 dB).

From the above results we can see that the PSNR value increased from the first filtering step to the refinement step. The PSNR value of the refinement step is large compared to the previous filtering steps.

The comparision of PSNR and MAE values of different filtering steps for the "Salesman", "Suzie", "Foreman", and "Rosebloom" sequences can be seen in Table I.

A. Statistical Analysis of PSNR Values

TABLE I
Comparision of PSNR (dB) Values.

	Filtering Steps	**PSNR(dB)**	**MAE**
Salesman	**1st**	**36.1248**	**15.87**
	2nd	**43.7062**	**2.76**
	3rd	**48.6028**	**0.89**
Suzie	**1st**	**34.5019**	**23.06**
	2nd	**38.3814**	**9.43**
	3rd	**40.7665**	**5.45**
Foreman	**1st**	**31.0957**	**50.52**
	2nd	**37.7796**	**10.84**
	3rd	**39.2492**	**7.72**
Rosebloom	**1st**	**36.4407**	**14.75**
	2nd	**46.6970**	**1.39**
	3rd	**51.5643**	**0.45**

From Table I we can see that the PSNR values of "Salesman","Suzie", "Foreman", and "Rosebloom" sequences increased from the first filtering step to third filtering step. The MAE values decreased from the first filtering step to third filtering step. The lower the MAE, the more similar the images.

V. CONCLUSION

In this paper, we have presented a new filtering frame work for color videos corrupted with random valued impulse noise. In order to preserve the details as much as possible, the noise is removed step by step. The detection of noisy color components is based on fuzzy rules in which information from spatial and temporal neighbors as well as from the other color bands is used. Detected noisy components are filtered based on median filtering techniques. The experiments showed that the proposed method out performs other state-of-the-art methods both in terms of objective measures such as MAE, PSNR and visually.

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